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Life Cycle Cost Model for Considering Fleet Utilization in Early Conceptual Design Phases

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Abstract

Cost prediction is commonly used when making decisions during the product development process. Oil and gas service companies must consider all life cycle costs for their business models. In addition to capital and operational expenditures, consideration of product utilization is essential. The cost of product failures, maintenance and repairs greatly impact the overall cost model. This paper describes an approach for simulating service availability and corresponding necessary fleet sizes based on existing life cycle cost models. A detailed case study presents the model viability and highlights key leverage points for cost reductions.

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Keywords: Life Cycle; Cost; Fleet size; Simulation; Service availability

1. Introduction

Oilfield service companies develop and manufacture technologies used for drilling and producing oil and gas. Typically, products are not sold; they are rented to customers as part of comprehensive service packages. Consequently, the companies are faced with operational costs to maintain, repair and transport products [1]. Over the entire life cycle of these technologies, operational costs are often many times greater than one-time capital expenditures. Project teams, therefore, must take all life cycle costs into account for a cost-efficient product. Life cycle costs are defined as "discounted cumulative total costs incurred by a specified function or item of equipment over its life cycle" [2].

Most costs are determined in the product's design stage. It is challenging, and in some instances not possible, to influence costs at a later stage [3-5]. In addition, estimated costs derived in early development stages are often not precise. Companies use models to compare different concepts and identify cost drivers. Spreadsheet-based software has been developed [1]. In addition to capital and operational costs, consideration of product utilization is essential. The time of product nonuse dictates the fleet size (number of uniform products) for a specific service demand. Increasing product utilization and minimizing the fleet size offers significant life cycle cost-saving potential.

State-of-the-art fleet size calculations are used in several industrial sectors. At the end of the 1970s Walmsley [6] published a fleet-size model for inter-city services. The model calculated the predicted number of trains to fulfill the service demand of a city network. In 2001, Field et al. from MIT [7] used a series of mathematical derivations to demonstrate the need for a fleet-centered approach in life cycle assessment of products in general. Halvorsen-Weare et al. [8] developed a model to optimize the fleet size of vessels that maintain offshore wind farms. Various models in the airline [9], car [10] and railway industries [11] were also recently published. These models are mathematical based, which makes them difficult to set up, modify and explain. In addition, their range of application is specific to products in one particular industrial sector.

The challenging estimation of fleet sizes concurrent with the early development process is rarely described in literature. Maintenance, repairs and other downtimes as well as

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operating service information need to be considered. This paper describes an approach to simulate the fleet size for different designs during the early development phases of oil and gas technologies. On basis of the life cycle costing model, the design utilization is simulated using the logistic software "Tecnomatix Plant Simulation". To facilitate use and avoid manual input errors, an interface between the Microsoft Excel-based Life Cycle Costing (LCC) model [1] and Plant Simulation is created. A case study shows example simulations.

2. Approach

In addition to the information from the existing LCC model, simulated service availabilities intend to support decision-making within the development process. The availability of a product greatly affects its life cycle cost. If a product is not available, follow-up costs can occur [12]:

- Warranty charges
- Revenue loss
- Costs to provide an alternative

For a service company, which owns its products, warranty charges do not need to be considered. Nevertheless, warranty or sustaining efforts can lead to significant cost throughout the product's lifetime. In addition, meeting the demand for a product is assumed to be satisfied by a specific number of products (fleet size). To optimize cost, the fleet size must be as small as possible, yet large enough to perform all assigned jobs reliably.

When a product is in maintenance, repair or on transport, it is not available for services. This situation must be considered when planning the fleet size. Ultimately, the increased number of products represents the previously mentioned costs for providing an alternative. The fleet size depends on the availability of the product. If product availability is low, more products and thus a greater fleet size must be manufactured and maintained, which should be considered in all life cycle cost calculations.

Product availability is calculated using the total utilization ratio. This value, in contrast to technical availability, contains organizational downtimes (e.g., transports). The total utilization is the quotient of useful life and busy time [13].

$$\text{Total Utilization Ratio} = \frac{\text{Utilization time}}{\text{Occupied time}} \tag{1}$$

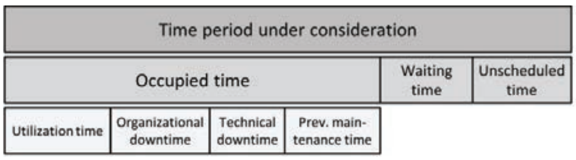

Fig. 1: Classification of different times in availability calculation [13]

The time period under consideration contains occupied, waiting, and unscheduled time. Occupied time includes all periods when the product is occupied, due to use or maintenance, or through organizational and technical downtimes. Against the background of the goal to minimize the fleet size, fully utilized products - without waiting and unscheduled times - can be assumed. The occupied (occ.) time results in the sum of utilization time, downtimes (downt.) and maintenance (maint.). The Total Utilization Ratio (TUR) can be expressed as follows:

$$\text{TUR} = \frac{\text{Occ. time - org. downt. - techn. downt. - prev. maint.}}{\text{Occ. time}} \tag{2}$$

The occupied time amounts 365 days per year. Maintenance and technical downtimes are deposited in the life cycle costing model. Organizational downtimes are considered via allowance values, e.g., for transports. As a result, all input quantities for the total utilization rate and the assimilated availability are determined.

3. Models

3.1. LCC Model

The life cycle costing model for drilling products (following named tools), introduced in 2014 [1], is an Excel-based spreadsheet with macros, programmed with Visual Basic for Applications. The model considers capital expenditures (CAPEX) as well as operational expenditures (OPEX), depicted in Fig. 2. CAPEX consists of the material cost of all parts in addition to assembly times. OPEX are divided into material, labor and third-party costs. Materials are differentiated as wear and consumable parts. Wear parts, which are mostly expensive components, are inspected during maintenance and are only replaced when necessary. In contrast, consumables such as O-rings and screws are replaced without inspection at a defined maintenance level. Labor cost is the product of working hours for maintenance and repair and the accordingly hourly rate. Third-party cost represents all repairs and inspections performed by external suppliers.

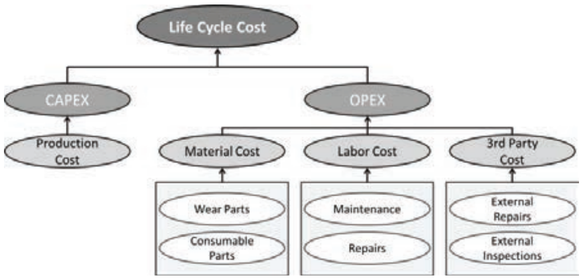

Fig. 2: Composition of cost in current model

All OPEX costs are normalized to hours of using the tool. For drilling services a common unit for lifetimes and maintenance intervals are circulation hours (CH). CH is the timeframe when the tool is in the well and drilling fluid is pumped through the system [1].

This approach makes cost estimations independent from changing market conditions. If operational costs would be calculated based on steady time intervals, the demand for services in the period would impact the overall cost. In addition, it is easier and more intuitive for subject-matter experts to estimate wear or necessary maintenance intervals in useful life.

In the future, the cost to provide an alternative when tools are out of service shall be part of the life cycle cost calculation in the model. The required fleet size must be determined with estimated data in the development process.

Some of the required data for the fleet size calculation is already deposited in the model:

- Frequency and duration of maintenances
- Frequency and duration of repairs and third-party labor

The following data must also be provided for the enhanced simulation:

- Number of consumers (in this case, the number of tools on drillings rigs)
- Duration of a mean operation of the tool on the rig
- Nonproductive times (transport, warehouse management)

The rigs and the mean operation time of the tools on it represent the demand of service. To guarantee comparable results, these values must be kept constant within a design comparison. Nonproductive times must also be considered as downtimes.

To calculate follow-up costs due to unavailability, the additional required tools must be calculated. Therefore, a benchmark is necessary to compare different concepts. This approach is also useful for new designs based on their preceding product. The difference between the simulated fleet size and the benchmark represents the number of additional tools. The production cost for these must be distributed to the entire fleet.

3.2. Fleet size simulation

To guarantee the usability of the life cycle costing model and to avoid complex differential equations, software for the fleet size simulation is needed. This software should be easy to use and supply an interface to Excel that operates in the backend. The software, "Plant Simulation by Tecnomatix," meets these requirements. It is used to model and simulate digital factories and therefore is specified for processes and logistic flows. Elements can be created by drag and drop and logical links.

The demand for service on a specific number of rigs is modeled as an array of parallel machines. A machine equates to one rig. The process time of a machine represents the duration of a mean operation. Maintenance and repair performances are also modeled in the form of machines. All machines are logical connected to a network. Tools flow from rigs to maintenance and repair elements. The distribution is set by arising frequency – determined by mean time between maintenance and repair. Nonproductive times, like transports, are substituted by buffers. If a rig has an open demand, a tool according to the first-in/first-out (FIFO) method in the stock is requested. Thus, a circular flow of the tools occurs (Fig. 3).

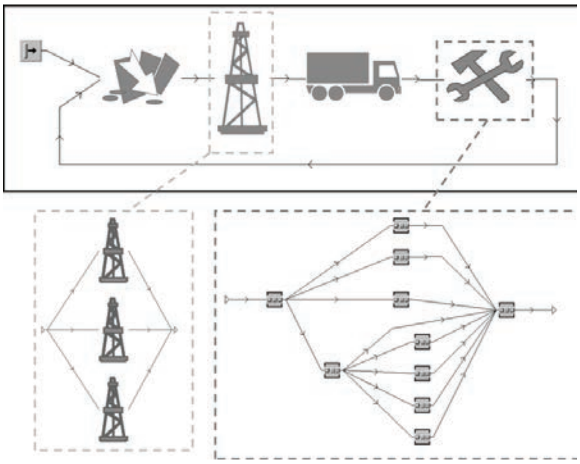

Fig. 3: Exemplary plant simulation network

The minimal fleet size depicts the smallest possible quantity of tools with fully utilized rigs. This number is identified by the simulation.

As discussed, the developed LCC model is based on a bottom-up approach to enable objective decision making through transparency of cost. The bottom-up approach also allows the continuous use of the LCC model, with ever-increasing detail starting in conceptual design phase until final field introduction.

3.3. Interface

For better usability, an interface between the Excel-based life cycle costing model and simulation software is necessary. This enables automated data transfer as well as a fast and secure execution of the simulation. The first input represents the minimum fleet size of the referenced benchmark to calculate the additional required tools. Order-related data, the number of operating rigs and the mean job time of a service, must also be entered (Fig. 4).

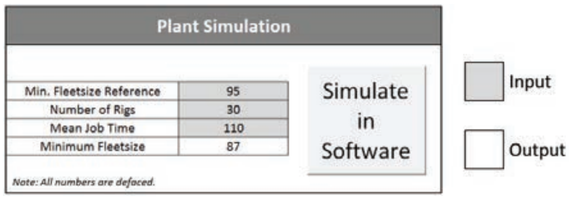

Fig. 4: Screenshot from Excel-based LCC model

The simulation software starts and requires data, such as repair times, to be transferred. The simulation runs through a given number of cycles and sends the result to Excel. No user inputs within plant simulation are required.

The difference between the simulated minimum fleet size and its reference - a preceding product or another concept - is the resulting number of tools, which need to be manufactured.

If more information from the simulation is requested, e.g., statistics of performed maintenances, a transfer of these values could be easily implemented into the program code.
The field of applications as well as cost and saving potentials are illustrated in the following case study.

4. Case study and validation results

A method of validating the fleet size model and two possibilities of implementing the developed model in early design are described. In all three instances actual cases are used.

4.1. Concept comparison

Before using the model to compare product concepts, it is obligatory to validate it with reality situations. For this, actual maintenance and operation values of the precursor benchmark product, which is already commercialized, are collected using advanced data mining. The data is aggregated from the ERP-system and from the intra-company maintenance and performance database and then processed. Based on this benchmark information, the current service is simulated. The result is the necessary fleet size which is used to fulfill the services on the fleet of drilling rigs. Therefore the model is validated and can be utilized to simulate future scenarios within product concept design.

Two different concepts of a current development project are simulated with the described approach. Their designs differ in various electronic parts, which results in different maintenance and repair requirements. Conceptual Design 1 (concept 1) contains cheaper parts than Conceptual Design 2 (concept 2). But as often the case, the cheaper parts have less lifetime expectancy than the more expensive ones that were plugged into concept 2. Therefore the first concept needs more frequent maintenance and repair cycles over its life time in comparison to the second concept. The simulation must identify if higher material cost for the second concept affects its life cycle cost.

Necessary data (s. chapter 3.1), e.g. maintenance and other down times, is estimated by a group of experts. The group consists of process developers, cost subject-matter experts, repair and maintenance specialists as well as manufacturing engineers. The simulation is performed for a specific number of drilling rigs, based on experience from the operating team. The results are presented in Fig 5. It shows the time slices of available tools for the particular minimal fleet size.

The first concept requires a fleet size of 61 to perform all services. Fewer tools cannot result in a guarantee of supplying all drilling rigs. The second concept has fewer downtimes, which results in a smaller required fleet size of 57. A further reduction is not possible, because occasionally no tool would be available. Thus, the second concept allows a reduction of the fleet size for the given service volume of approximately 7%.

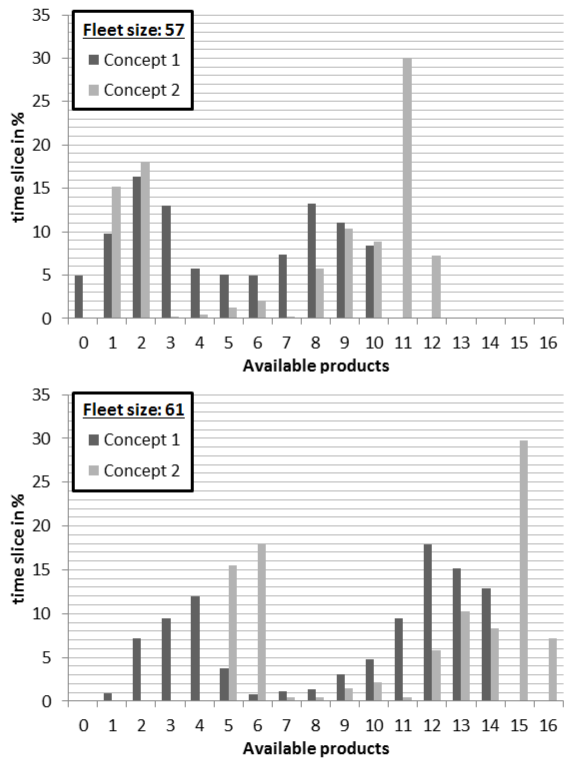

Fig. 5: Results of fleet size simulation

Afterwards, the reduced fleet size must be converted into real costs. In the first place, a smaller fleet of seven percent also reduces the overall CAPEX value by the same percentage. This savings can be allocated to all tools of the fleet. The outcome is a significant potential saving. In the case of choosing concept one for any reason, the larger fleet should be expressed as opportunity cost (OC) to each tool. The difference between the fleet sizes (FZ) of concept one (61) and concept two (57) amounts to four tools. Multiplied with the production cost of a tool (CAPEX), the total excess expenditures are calculated. These become - analog to the savings - allocated to all tools of the fleet.

$$\text{OC per tool} = \frac{\text{CAPEX} \times (\text{FZ concept 1 - FZ concept 2})}{\text{FZ concept 2}} \quad (3)$$

Better operational values, like interval and duration of maintenances, reduce the fleet and are described as CAPEX. The influence of a smaller fleet size on OPEX is, in contrast, difficult to determine because the service volume is the same. The reduction has no meaningful influence on which tool of the fleet is maintained. A bigger fleet size could avoid some transportation; a smaller fleet may need less administration. In relation to the big influence on CAPEX, these aspects are negligible.
Before considering fleet sizes there was no clear, certain result as to which concept was more cost efficient, meaning if higher CAPEX of the second concept was amortized by lower

OPEX over the tool lifetime. The fleet size reduction clarifies that concept two should be chosen.

4.2. Determination of MTBM

Working with the LCC model and fleet size simulation offered another field of application. The model was developed to determine fleet sizes for conceptual products as presented in the previous chapter. Moreover the Excel-interface enables an easy and fast use. It is possible, through varying the parameters, to determine the relationship between the input values and their impact. So, a manually executed sensitivity analysis can be performed. Consequently, it is possible to turn the application of the model, which is described in following.

In this case study, the number of tools as well as the demand for a service is known. A larger fleet size would result in a negative business case and in an uneconomic project. The combination of LCC model and simulation enables determination of the necessary availability to meet the maximum fleet size goal. The following parameters can be varied:

- Mean time between maintenance, repairs and third-party labor
- Duration of maintenance, repairs and third-party labor

The design has no influence on organizational downtimes, so they are kept constant. Therefore, the design teams can determine if their concepts meet the requirements. These teams can determine which parameters have the biggest impact on the overall result and which values are not worth the effort to optimize anymore. So the increase of the mean time between maintenance can easy be expressed in a smaller fleet size and less cost.

5. Conclusion and outlook

The follow-up cost of unavailability can be determined by the interaction of the life cycle costing model and fleet size simulation. The simulation enables a fast and easy determination of necessary fleet sizes for different design concepts. Through the consideration of follow-up cost in early development stages due to maintenance and downtimes, cost optimization as well as a reduction of the fleet size is possible. Even a minimization of tool inventory is feasible, if concepts are chosen on the basis of the follow-up cost.

In the future, an automated sensitivity analysis of the parameters can simulate different scenarios and be used as an optimization tool. Further steps in providing a more detailed simulation model, e.g., with a spare parts inventory, can also result in more precise cost calculations.

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